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VORTICITY FIELD EVOLUTION IN A FORCED WAKE

Richard Cohn and Manoochehr Koochesfahani
Mechanical Engineering Dept.; Michigan State University

The purpose of this work is to quantify the vorticity evolution in the flow field of the forced wake of a splitter plate inside a confining geometry. The interest in this flow stems from the fact that forcing a low Reynolds number 2-D wake can lead to a highly three-dimensional flow and a large increase in mixing [1]. Our recent estimates, based on chemically reacting LIF measurements, report the amount of molecularly mixed fluid in terms of mixed-fluid fraction to be 2.5 to 3 times larger than that in high Reynolds number natural two-stream mixing layers [2]. Both reacting and non-reacting LIF data connect this increase in mixing to the downstream evolution of the streamwise vorticity, which is generated by the reorientation and stretching of spanwise vorticity near the side walls of the flow facility. It is believed that understanding the vorticity interaction with walls, its dynamics, and downstream evolution will be helpful to an overall strategy for mixing enhancement and control.

The measurements are carried out by Molecular Tagging Velocimetry (MTV). This technique takes advantage of molecules with long-lived excited states for non-intrusive, multi-point measurements of various fluid dynamical quantities. Small regions of the flow are tagged by a laser and their subsequent evolution is monitored over the luminescence lifetime of the molecule. A two-detector imaging system is used to acquire an image of the initially tagged regions and a subsequent image of these regions convected by the flow over a prescribed time delay Δt later. The Lagrangian displacement vectors from such image pairs are computed using a spatial correlation technique. The details of these developments can be found in References [3-5]. The particular flow investigated here is highly three dimensional, and this application highlights the capability of MTV to make measurements when strong out-of-plane motions are present.

The time series of the instantaneous velocity vectors (u, v components) in the streamwise (x-y) plane have been obtained at several spanwise (z) locations. The spanwise vorticity field ω_z is estimated from the measured velocity field by a second-order finite difference scheme. These data allow us to investigate the temporal and downstream evolution of ω_z at different forcing amplitudes. Typical data at mid-span are shown in Figure 1. The vorticity field of the alternating-sign vortex array and its spatial arrangement, previously noted through LIF visualization, is quantified. It can be seen that the lateral spacing of the vortex array reduces and the peak vorticity increases as the forcing amplitude increases. Note also that the decrease in the peak vorticity due to diffusion, as the flow moves from left to right, is captured. Results indicate that the momentum deficit in the wake tends towards zero for increasing forcing amplitude, consistent with the reduction of the lateral spacing of the vortex array.

These data have been complemented by measurements of the velocity vectors (v, w components) in the spanwise (y-z) plane and the streamwise vorticity field ω_x. Typical results showing the downstream evolution of ω_x are shown in Figure 2. In this figure, the streamwise flow

direction is ~~out~~ out of the page and the imaged area corresponds to the right half of the test section cross sectional area. The vorticity field of the alternating-sign streamwise vortex pair near the side wall (z = - 4 cm) at early x locations, previously noted through LIF visualization, is quantified. As the flow proceeds downstream, the spatial arrangement and dynamics of the streamwise vorticity become more complex, the peak value of the vorticity decreases and the region containing the streamwise vorticity moves away form the side wall towards the center ($z = 0$) of the test section. An important result is that the streamwise vorticity has a peak value in excess of 70% of the peak spanwise vorticity.

We are in the process of combining the spanwise and streamwise vorticity data to construct a volumetric picture of the vorticity field showing the details of how the flow three-dimensionality evolves downstream. The ultimate goal is to link the dynamics and evolution of the vorticity field to the increased mixing quantified previously.

References

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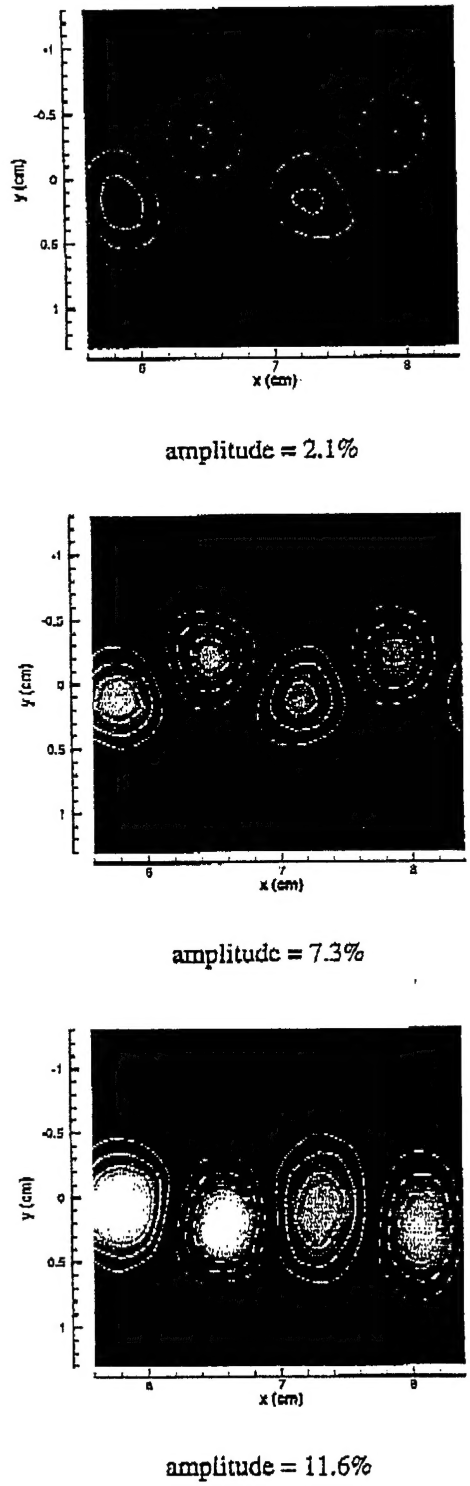

Figure 1. Wake ω_z distribution at midspan for one phase in the forcing cycle for different amplitudes. Vorticity contours are ±5, ±10, ±15, ... (s^{-1}). Dashed lines indicate negative vorticity.

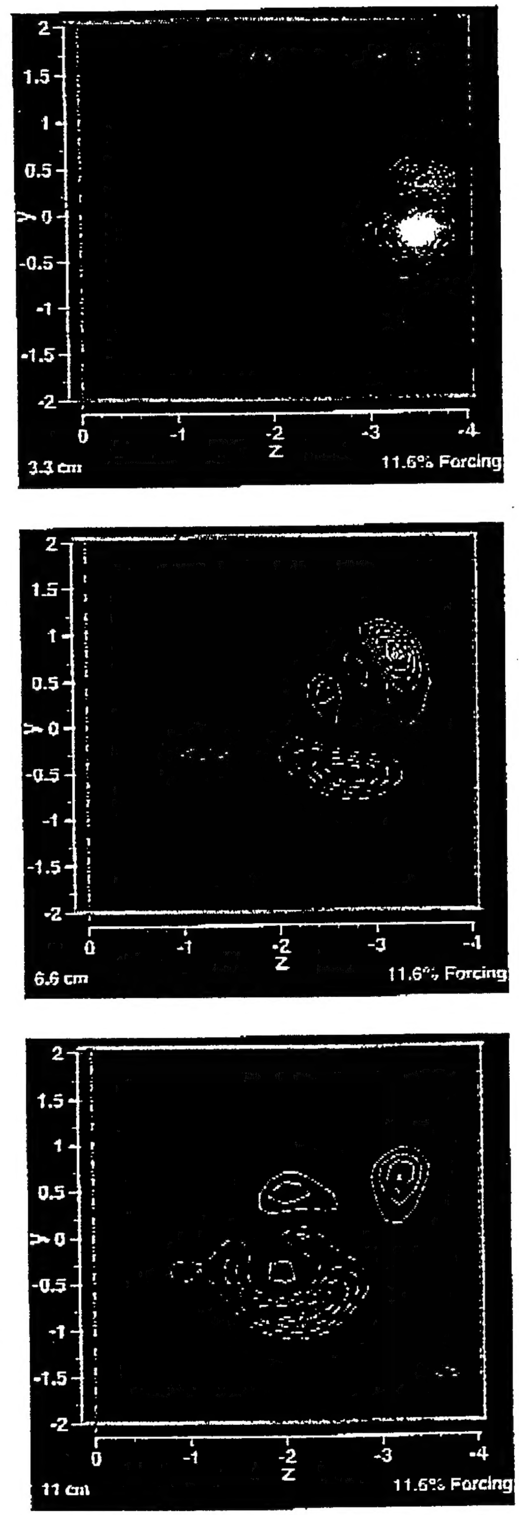

Figure 2. Downstream evolution of ω_x in the wake for one phase in the forcing cycle. Data planes are at x = 3.3, 6.6, and 11 cm. Contours are ±3, ±5, ±7, ... (s^{-1}). Dashed lines indicate negative ω_x.